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STORING DATA TO MAGNETIC TAPE BOTH TO ONE SET OF TRACKS AND IN THE SAME OPERATION REWRITTEN TO ANOTHER SET OF TRACKS

DOCUMENT INCORPORATED BY REFERENCE

Coassigned U. S. Patent Application Serial No. 10/058,101 is incorporated for its showing of the initial writing of data to magnetic tape, accumulating that data and subsequently recursively writing the accumulated data to the magnetic tape in a sequence.

FIELD OF THE INVENTION

This invention relates to storage of data to magnetic tape, and, more particularly, to storage of data which is to be physically written to tape before a command complete response can be made, so that the entity sending the data is able to erase its data, knowing that a copy physically exists on magnetic tape.

BACKGROUND OF THE INVENTION

Magnetic tape provides a means for physically storing data which may be archived or which may be stored in storage shelves of automated data storage libraries and accessed when required. Data stored in this manner has an aspect of permanence which allows copies of the data stored in memory or disk at a host system to be erased, knowing that a copy exists on

magnetic tape. The available storage space at the host system is relatively expensive, and there is a desire to release the storage space as soon as possible. Hence, data is typically transferred through an intermediate staging buffer, such as a hard disk, to the tape drive, and there is also a desire to release and overwrite the staging buffer as soon as possible.

Thus, it is often desirable to "synchronize" the data.

"Synchronized data" is defined as data or other information which is subject to a "synchronizing event" or similar command requiring the tape drive to not return "Command Complete" to a write type of command, or an indication that the command has been or will be successfully executed, until it has actually committed the data to media, specifically, the magnetic tape. As the result, if power is lost, the data can be recovered from the tape, whereas it may not be recoverable from a volatile DRAM storage of the tape drive buffer.

One example of a synchronizing event is a Write Filemark command with the Immediate bit set to "0". This means that the drive is not to respond immediately, but instead is to respond when the command has completed, meaning that any data sent as part of the command is written out to tape. A specialized case of a Write Filemark command is where the number of Filemarks field is also set to "0", meaning that the Write Filemark command has no data of its own, and thus the sole purpose of the command is to assure that all data which precedes the command must be written to tape before a command complete is sent. Hence, this command is often referred to as a "Synchronize" command, as is known to those of skill in the art.

Another example of a synchronizing event is a host selectable write mode known to those of skill in the art as "non-buffered writes", where an implicit synchronize must be performed

after each record is written from the host. "Command Complete" is not returned for any write command until the data is successfully written on media.

Herein, writing any data record, group of records, or other mark, is defined as a "transaction", and writing such data record, etc., as the result of a synchronizing event is defined as a "synchronized transaction".

A difficulty with respect to magnetic tape is that the data is recorded sequentially without long gaps between data sets, whereas synchronized transactions are stored in separate bursts for each synchronizing event, with a noticeable time period before writing the next transaction. This requires that the tape drive "backhitch" after writing the synchronized transaction in order to write the next transaction closely following the preceding transaction. Tape is written or read while it is moved longitudinally at a constant speed. Hence, a backhitch requires that the tape be stopped, reversed to beyond the end of the previous transaction, stopped again, and accelerated up to speed in the original direction by the time that the end of the previous transaction is reached. As is understood by those of skill in the art, the backhitch process consumes a considerable amount of time, and, if a large number of small synchronized transactions are to be stored, the throughput of the tape drive is reduced dramatically. As an example, backhitch times can vary from about half a second to over three seconds.

The incorporated '101 Application solves the problem by writing synchronized data transactions to magnetic tape without stopping the tape, perhaps leaving gaps between the transactions, accumulates the synchronized transactions in a buffer, and subsequently rewrites the accumulated transactions from the buffer to the magnetic tape in a sequence. This is now called "Recursive Accumulating Backhitchless Flush", or "RABF", in the art. With large sized

transactions relative to buffer size, it is possible that the buffer will fill with the accumulated transactions relatively quickly, forcing the recursive writing of the transactions and holding off the receipt of additional data during the recursive writing, such that non-RABF performance will approach that of RABF recording.

SUMMARY OF THE INVENTION

The present invention comprises a recording system, a magnetic tape drive, a method, a computer program product, and control logic for writing data to magnetic tape.

A recording system of a magnetic tape drive is operated so as to cause one separate set of write heads to write data to magnetic tape, and, during the same operation, to cause another separate set of write heads to rewrite data to magnetic tape. The writing may be in parallel and may be simultaneous.

In one embodiment, having at least one buffer and a recording system, a controller of the recording system operates the buffer(s) and the recording system to provide data from the buffer(s) to cause a separate set of the plurality of write heads to write the provided data to tracks of magnetic tape; and the controller saves the provided data at the buffer(s). During the same operation, the controller operates the buffer(s) and the recording system to provide saved data from the buffer(s) to cause another separate set of the plurality of write heads to rewrite the saved data to other tracks of the magnetic tape in a continuous arrangement. Thus, during the same operation, the separate sets of write heads, write data to magnetic tape, and rewrite saved data to the magnetic tape, perhaps simultaneously writing with the separate sets of write heads.

In a further embodiment, wherein the data is in the form of data transactions, the controller additionally responds to an indication that the data transactions are to be written to magnetic tape as synchronized data transactions, and operates the buffer(s) and the recording system to cause a separate set of the write heads to write the data transactions to tracks of magnetic tape in a manner which is discontinuous due to having to empty the buffer in response to synchronizing commands, and saves the data transactions at the buffer(s). During the same operation, the controller operates the buffer(s) and the recording system to cause another separate set of the plurality of write heads to rewrite saved data transactions to other tracks of the magnetic tape in a continuous arrangement.

In a still further embodiment, the controller additionally operates the recording system to cause the separate set of the plurality of write heads to write separator signals between the discontinuously written data transactions.

In another embodiment, the controller additionally, for each synchronized data transaction, returns a command complete at an interface upon completion of the writing a synchronized transaction to tracks of magnetic tape in a discontinuous manner.

In a further embodiment, wherein the magnetic tape drive additionally comprises a wrap control for translating the plurality of write heads laterally to different sets of wraps of the tracks of magnetic tape, such that either of the sets of write heads may write data to at least some of the wraps; the controller operates the wrap control, the buffer(s) and the recording system to write data from the buffer(s) to one of the wraps, the data to be saved, and to rewrite saved data on another wrap, potentially simultaneously; and to seek to an alternate wrap to continue to write the provided data to be saved, and to seek back to the one wrap and the another wrap. The rewriting

of saved data can then continue at the another wrap as does the writing of the provided data at the one wrap.

In a still further embodiment, the wraps are accessed in a sequence, such that a wrap having the data to be saved follows in the sequence a wrap at which the data is rewritten, such that a continuous string of wraps are first written with the data to be saved, and then are overwritten with the rewritten data.

In another embodiment, wherein the magnetic tape drive additionally comprises a plurality of read heads for reading from magnetic tape while the magnetic tape is moved longitudinally with respect to the plurality of read heads, and a read data system, the controller additionally operates the read data system to read one of the wraps at a time with one set of the plurality of read heads.

In another embodiment, wherein the magnetic tape drive additionally comprises a wrap control for translating the plurality of write heads laterally to different wraps of the tracks of magnetic tape, the controller operates the wrap control, the buffer(s) and the recording system to write data from the buffer(s) to one of the wraps in a sequence of the wraps, and to rewrite the saved data to another of the wraps that is offset from the one of the wraps.

In a further embodiment, the controller selectively operates the buffer(s) and the recording system to provide data from the buffer(s) to cause a separate set of the plurality of write heads to write the provided data to tracks of magnetic tape, saving the provided data; and, during the same operation, operates the buffer(s) and the recording system to provide saved data from the buffer(s) to cause another separate set of the plurality of write heads to write the saved and provided data to other tracks of the magnetic tape; and selectively operates the buffer(s) and

the recording system to provide data from the buffer(s) to cause the plurality of write heads to write provided data to tracks of magnetic tape, comprising up to all sets of the write heads.

In still another embodiment of the present invention, saved and discontinuously written data transactions may be temporarily rewritten while the discontinuous writing of data transactions continues, allowing the original discontinuously written transactions to be overwritten before the data transactions are finally rewritten.

In a still further embodiment, wherein the magnetic tape drive additionally comprises a plurality of read heads for reading from magnetic tape while the magnetic tape is moved longitudinally with respect to the plurality of read heads, the controller additionally selectively operates the read data system to read one of the wraps at a time with one set of the plurality of read heads; and selectively operates the read data system to read a plurality of the wraps at a time with the plurality of read heads.

For a fuller understanding of the present invention, reference should be made to the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of magnetic tape drive with a magnetic tape cartridge, which tape drive implements the present invention;

FIG. **2** is a diagrammatic illustration of synchronized data written on magnetic tape employing a prior art methodology with backhitches;

FIG. **3** is a diagrammatic illustration of synchronized data written on magnetic tape employing a prior art backhitchless flush and recursive write methodology;

FIG. **4** is a schematic representation of a tape head of the magnetic tape drive of FIG. **1** and a length of magnetic tape with a plurality of separate servo bands;

FIG. **5** is a schematic representation of a prior art servo band of the magnetic tape of FIG. **4** and index positions of a servo transducer as it tracks the servo band;

FIG. **6A** and **6B** are diagrammatic illustrations of data written on magnetic tape in accordance with the present invention;

FIG. **7** is a diagrammatic illustration of an alternative arrangement of data written on magnetic tape in accordance with the present invention;

FIGS. **8A** and **8B** are diagrammatic illustrations of wraps of a magnetic tape as data is written in accordance with the present invention;

FIG. **9** is a diagrammatic illustration of wraps of a magnetic tape as data is written in accordance with another aspect of the present invention;

FIGS. **10A** and **10B** are diagrammatic illustrations of wraps of a magnetic tape as data is written in accordance with another embodiment of the present invention; and

FIG. **11** is a flow chart depicting embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention is described in preferred embodiments in the following description with reference to the Figures, in which like numbers represent the same or similar elements. While this invention is described in terms of the best mode for achieving this invention's objectives, it will be appreciated by those skilled in the art that variations may be accomplished in view of these teachings without deviating from the spirit or scope of the invention.

Referring to FIG. **1**, a tape drive **10** is illustrated which may implement the present invention. The tape drive provides a means for reading and writing information with respect to a magnetic tape cartridge **11**. A cartridge and associated tape drive are illustrated, such as those adhering to the Linear Tape Open (LTO) format. An example of a single reel tape drive is the IBM 3580 Ultrium magnetic tape drive based on LTO technology. A further example of a single reel tape drive and cartridge is such as that discussed in U.S. Patent No. 5,432,652, Comeaux et al., issued July 11, 1995. Another example of a single reel tape drive is the IBM 3590 Magstar magnetic tape drive and associated magnetic tape cartridge. An example of a dual reel cartridge is the IBM 3570 magnetic tape cartridge and associated drive.

As is understood by those of skill in the art, a magnetic tape cartridge **11** comprises a length of magnetic tape **14** wound on one or two reels **15, 16**. Also as is understood by those of skill in the art, a tape drive **10** comprises one or more controllers **18** for operating the tape drive in accordance with commands received from a host system **20** received at an interface **21**. The tape drive may comprise a standalone unit or comprise a part of a tape library or other subsystem.

The tape drive **10** may be coupled to the host system **20** directly, through a library, or over a network, and employ the Small Computer Systems Interface (SCSI), Fibre Channel Interface, etc.

The magnetic tape cartridge **11** may be inserted in the tape drive **10**, and loaded by the tape drive so that one or more tape heads **23** reads and/or writes information with respect to the magnetic tape **14** as the tape is moved longitudinally by one or more motors **25**. The magnetic tape comprises a plurality of parallel tracks, or groups of tracks. In some formats, such as the LTO format, above, the tracks are arranged in a serpentine back and forth pattern of separate wraps, as is known to those of skill in the art. Also as known to those of skill in the art, a wrap control system **27** electronically switches to another set of read and/or write heads, and/or seeks and moves the read and/or write heads **23** laterally of the magnetic tape, to position the heads at a desired wrap or wraps, and, in some embodiments, track follows the desired wrap or wraps. The wrap control system may also control the operation of the motors **25** through motor drivers **28**, both in response to instructions by the controller **18**.

Controller **18** also provides the data flow and formatting of data to be read from and written to the magnetic tape, in accordance with the present invention, employing a buffer **30** having a plurality of separate data flow outputs **125**, **126**, and, employing a recording system having multiple recording channels **132** and **133**, and a read data system **134** having multiple read channels. The terminology "recording channel" and "read channel" is employed herein to respectively provide data to or to read data from a set of write heads and/or read heads to write and/or read in parallel. A plurality of recording channel circuits and logic and read channel circuits and logic may comprise a recording channel and a read channel, respectively.

As discussed above, magnetic tape provides a means for physically storing data which may be archived or which may be stored in storage shelves of automated data storage libraries and accessed when required. Tape drives often employ a "read after write" process to insure that the data is written correctly to provide an aspect of permanence. This permanence allows copies of the data stored in memory or disk at the host system **20** to be erased, knowing that a correct, or at least correctable with ECC with margin, copy exists on magnetic tape.

The available storage space at the host system is relatively expensive, and there is a desire to release the storage space as soon as possible. Hence, data is typically transferred through an intermediate staging buffer, such as a hard disk, to the tape drive, and there is also a desire to release and overwrite the staging buffer as soon as possible. In the instant example, the staging buffer, if any, is considered to comprise part of the host system **20**.

In order to release the staging buffer, it is necessary to have an assurance that the data has actually been recorded on the magnetic tape **14**, and is not just in a volatile DRAM storage, such as buffer **30**, when it may be lost if power to the buffer or to the drive is lost. Thus, it is often desirable to "synchronize" the data, requiring the tape drive to not return "Command Complete" to a write type of command, or an indication that the command has been or will be successfully executed, until it has actually committed the data to media, specifically, the magnetic tape **14**. Once the data has been written to the magnetic tape, if power is lost, the data can be recovered from the tape, whereas it may not be recoverable from a volatile DRAM storage of the tape drive buffer.

Various examples of synchronizing events which have the effect of synchronizing the data are known to those of skill in the art. One example of a synchronizing event is a Write

Filemark command with the Immediate bit set to "0". This means that the drive is not to respond immediately, but instead is to respond when the command has completed, meaning that any data sent as part of the command is written out to tape. A specialized case of a Write Filemark command is where the number of Filemarks field is also set to "0", meaning that the Write Filemark command has no data of its own, and the only meaning of the command is that all data which precedes the command must be written to tape before a command complete is sent. Another example is a host selected non-buffered write mode implicitly requiring a synchronize for each record.

Referring to FIG. **2**, data is typically recorded on magnetic tape sequentially with only short gaps **40** between data sets, for example between data sets **31** and **32, 32** and **33**, etc. These gaps may be written with an Interblock Gap (IBG) pattern, or may comprise a Data Set Separator (DSS) pattern **40**, as is known to those of skill in the art. The gap may comprise an actual unrecorded portion and a portion that is recorded. For example, the LTO format DSS comprises a tone pattern between data sets. As discussed above, the tape is written or read while motors **25** of FIG. **1** move the tape longitudinally. Data typically comprises a string of records arranged in data sets, each with a DSS, which are written with nominal spacing. Only occasionally, typically when the buffer is empty, is the tape stopped.

However, if the data is synchronized, it must be immediately written to tape from the buffer, and only after the synchronized transaction has been written to tape is the transaction erased from the buffer and overwritten, such that it cannot be the subject of a continuous data flow. Hence, synchronized transactions instead must be written immediately in separate bursts for each synchronization event. As the result, after one data set is written for a synchronized

transaction, in the prior art of FIG. **2**, to insure that the data sets are closely spaced, the controller **18** of FIG. **1** typically operates the servo system and motor drivers to stop the tape after the data set. Some finite distance and finite time is required to stop the tape, and the tape is then "backhitched", reversed to beyond the end of the previous data set, stopped again, and accelerated up to speed in the original direction by the time that the end of the first data set is reached, so that the DSS and the next data set may be written. As is understood by those of skill in the art, the backhitch process consumes a considerable amount of time.

As discussed above, if a large number of synchronized transactions are to be stored, the throughput of the tape drive is reduced dramatically.

In the example of FIG. **2**, records **50-53** are synchronized. A transaction may comprise hundreds of records, but only transactions of one record each are illustrated for descriptive purposes herein. If a transaction comprised of a record, or group of records, ends in the middle of a data set, then an End Marker (EM) is written to signal that the remainder of that data set is empty. Synchronized transactions often can be multiple data sets in size, but are shown, for the purpose of illustration, as separate data sets, and are illustrated in FIG. **2** as data records **50-53** in data sets **31-34**. Thus, the prior art process requires that the tape drive **10** backhitch (shown by arrow **71**) after writing data set **31** (to synchronize transaction record **50**), to be positioned to write data set **32** with a minimum amount of DSS pattern in between; to backhitch **72** after writing data set **32** to synchronize transaction record **51**, and write data set **33**; etc. The process continues until all of the synchronized data has been written.

FIG. **3** illustrates the "Recursive Accumulating Backhitchless Flush", or "RABF", approach of the incorporated '101 Application, which solves the problem by writing

synchronized data transactions to magnetic tape without stopping the tape, perhaps leaving gaps between the transactions, accumulates the synchronized transactions in a buffer, and subsequently rewrites the accumulated transactions from the buffer to the magnetic tape in a sequence. This approach reduces the number of backhitches for the synchronized data.

In one example, the controller detects synchronized received transaction record **50** of FIG. **3** stored in the buffer; writes the detected synchronized transaction record **50**, with EM **60**, from the buffer to the magnetic tape as data set **80**; leaves an elongated gap, comprising an unrecorded gap and/or written separator signals **90** (e.g., DSS) to the magnetic tape following the written synchronized transaction record **50** (data set **80**), continuing the gap with or without separator signals **90** until a subsequently received synchronized transaction **51** (data set **81**) is written to the magnetic tape following the separator signals; and repeats the detection of a synchronized received transaction (e.g., record **51**), writing the detected synchronized transaction (as data set **81**), and writing the gap of separator signals (e.g., separator signals **91**), etc., for each succeeding detected synchronized received transaction, such that the tape is moved longitudinally during the repeated writing without stopping. Thus, there is no backhitch, the tape drive continues to write the synchronized transactions without stopping.

To complete the example of FIG. **3** for the four illustrated synchronized transaction records **50-53**, the next synchronized received transaction **52** is detected, and is written as data set **82**, and the gap separator signals (e.g., separator signals **92**) are typically written for some or all of the distance until the next detected synchronized received transaction **53** is written as data set **83**, etc.

Thus, no backhitch is required, saving considerable processing time for completing the process for writing all of the synchronized data.

Then, in a further example, also illustrated by FIG. **3**, space on the magnetic tape is saved by recursively writing the synchronized data to separate wraps. To preserve the synchronized transactions **50-53** in the event that power is lost, the data sets **80-83** are considered as work copies of the transactions. Once the transactions have been recursively written, the work copies are abandoned and may be overwritten.

First, the controller detects a pattern of synchronized transactions to be written to the magnetic tape. A pattern may comprise a predetermined number of consecutive synchronized transactions of less than a certain length. As one example, a pattern may comprise two consecutive synchronized transactions, each having a length less than some number of data sets. As discussed above, the typical synchronized transaction is written to tape, and then the transaction is erased from the host system with the assurance that the transaction has been written to tape and will not be lost as the result of a power loss.

The controller writes each detected synchronized transaction, illustrated as a record **50-53**, of the detected pattern from the buffer to the magnetic tape, e.g., as data sets **80-83**, above. Previous synchronized transactions of the detected pattern may be excluded, having already been written in the manner discussed above before the pattern is detected. Thus, in FIG. **3**, the previous synchronized transactions may comprise the previous data **99**. Upon writing each synchronized transaction of the detected pattern from the buffer to the magnetic tape, the controller accumulates the synchronized transaction in the buffer; and subsequently recursively writes the accumulated transactions from the buffer to the magnetic tape in a sequence, e.g.,

illustrated as data sets **100, 101**. The recursive writing may comprise a backhitch to place the recursively written accumulated transactions following the preceding data **99**, and with the nominal gap.

Thus, the synchronized transactions **50-53** have been immediately written to the magnetic tape, and preserved against a power loss at the buffer, as work copies in data sets **80-83**, while also being accumulated in the buffer, and then recursively written to immediately follow the preceding data **99** in data sets **100,101,** saving space. Once the transactions have been recursively written, meaning that the data has been rewritten, the work copies **80-83** may be overwritten.

The point at which the accumulated synchronized data is recursively written may comprise the termination of the pattern of synchronously written transactions, may comprise a predetermined threshold, such as the limit of capacity of the buffer to accumulate data records, or may comprise the limit of capacity of the work space for the work copies **80-83** and their separator signals **90-92**.

As discussed above, with large sized transactions, it is possible that the buffer will fill with the accumulated transactions relatively quickly, forcing the recursive writing of the transactions and holding off the receipt of additional data during the recursive writing, such that non-RABF performance will approach that of RABF recording.

FIG. **4** illustrates a magnetic tape **14**, the magnetic tape having a plurality of separate longitudinal servo bands **111, 112, 113** and **114**, which are laterally positioned on the magnetic tape, and with data tracks positioned between the servo bands. The tape head **23** comprises a number of separately addressable data read and/or write heads **117**, which read and/or write data

with respect to a number of parallel data tracks, and is provided with a separate servo head, or servo heads **120**, **121**, which are offset from the data read and/or write heads **117**, so as to track follow the servo track and allow the data read and/or write heads to be guided along the data track or tracks.

FIG. **5** illustrates one type of prior art servo band comprising a timing based servo pattern of the type described in US Patent No. 5,689,384, which comprises patterns of transitions recorded at more than one azimuthal orientation across the width of the servo band, and which are therefore non-parallel. The lateral position is determined as a ratio of two servo pattern intervals, one pattern interval employing parallel transitions such as two bursts **140** in separate patterns, and the other pattern interval employing transitions which are parallel to themselves, but not parallel to the first burst of transitions such as between burst **140** and burst **141**. Each servo band may have a plurality of indexed defined servo positions, such as 6 separate indexed defined servo positions **160**, **161**, **162**, **163**, **164** and **165** for a single servo band. Alternative types of servo bands are known to those of skill in the art, and the present invention may be implemented as well with respect to other servo bands.

Referring to FIG. **4**, the data read and/or write heads **117** are typically shared between various data tracks or groups of data tracks, and are moved between tracks or groups of tracks in the lateral direction of the tape. Each of the servo bands **111**, **112**, **113** and **114**, provides the servo guidance for groups of data tracks, and the servo head **120**, **121** of the tape head is repositioned laterally within a servo band at the various index positions to cause the data read and/or write heads **117** to access different data tracks, and is repositioned laterally to another servo band to access still further data tracks. In one example, the servo bands are spaced apart to

span the data tracks, which are located between the servo bands. This places a servo band close to the corresponding data tracks to reduce the span between the outer read and/or write elements and the servo band, and reduce sensitivity to changes in tape width between the time data is written and read back. To insure that the servoing is precise, two servo transducers **120, 121** may be provided at either end of the tape head, straddling the data read and/or write heads. The lateral positioning may be obtained from either of the two servo bands, or by averaging or otherwise comparing data from the two servo bands.

Referring to FIGS. **1** and **4**, in accordance with the present invention, the controller **18** may select a set of the write heads **117** and provide data from one or more selected separate data flow outputs **125**, **126** of the buffer **30**, for example, via a selected recording channels **132** and **133**, to the selected set of write heads **117**. The ability to select write heads is known in the art, employed, for example, if one set of write heads is used to write in one direction of tape motion, and a different set of write heads is used to write in the opposite direction. The same is true of read heads. In accordance with the present invention, however, separate sets of heads are selected to write data in the same direction, perhaps simultaneously. Alternatively, the recording channels **132** and **133** may comprise circuitry that is arranged to provide data to given write heads, and the recording channels are selected to thereby select the set of write heads **117**.

This has the effect of writing different wraps of data at the same time. For example, if the number of write heads is doubled from that of the prior art tape drive, the write heads may be arranged so that two wraps may be written simultaneously by the write heads of the tape head. The same is true for read heads, necessary for read-while-write functionality. Those of skill in

the art understand that the spacing of the heads **117** and the operation of the wrap control **27** may be arranged such that the wraps are compatible with the wraps of a tape head with fewer heads.

The buffer **30** may comprise a single buffer that has separate data flow outputs **125, 126,** for example, that are time slice multiplexed, or which are separately accessed, and which address separate segments of the buffer. Alternatively, buffer **30** may comprise multiple buffers that are employed for different purposes.

Controller **18** may comprise at least one programmable computer processor operating under the control of program code. The programmable computer processor may comprise any processor or microprocessor device known in the art. The method of the present invention may be provided in the form of a computer program product usable with a programmable computer processor having computer readable program code embodied therein, and may be supplied to the programmable computer processor in any of various ways as are known to those of skill in the art. Alternatively, controller **18** may comprise discrete logic, ASIC (application specific integrated circuit), FPGA (field programmable gate array), etc.

Referring to FIGS. **1, 4, 6A, 6B** and **7**, in accordance with the present invention, the magnetic tape drive **10** is operated so as to cause one separate set of the write heads **117** to write data to magnetic tape **14**, and, during the same operation, to cause another separate set of the write heads **117** to rewrite data to magnetic tape. The writing may be in parallel and may be simultaneous.

In this manner, data that is being supplied from a host system **20** and that is to be written to magnetic tape **14**, is supplied, via interface **21** to buffer **30**. If the data is indicated as being synchronized, such that it must be immediately written to tape from the buffer, and only after the

synchronized transaction has been written to tape, can the host system overwrite the locally stored copy of the data, the synchronized transactions must be written immediately to magnetic tape **14** in separate bursts for each synchronization event.

In one embodiment of the present invention, controller **18** operates the buffer(s) **30** and the recording system **132, 133** to provide data from an output of the buffer to cause a separate set of the plurality of write heads to write the provided data to tracks of magnetic tape. Thus, the data is written to magnetic tape **14** immediately, and, if in the form of synchronized transactions, the data transactions are written to tracks of magnetic tape in a discontinuous manner from the buffer(s). In a further embodiment, the controller **18** additionally operates the recording system to cause the separate set of the plurality of write heads to write separator signals between the discontinuously written data transactions. In a further embodiment, the controller **18** additionally, for each synchronized data transaction, returns a command complete at interface **21** upon completion of the writing a synchronized transaction to tracks of magnetic tape in a discontinuous manner.

In the example of FIG. **6A**, the magnetic tape drive writes the transactions to the magnetic tape on one of the wraps **170** without stopping. For example, transaction **175**, provided from the buffer **30**, is written to the magnetic tape; leaving an elongated gap, comprising an unrecorded gap and/or written separator signals **180** (e.g., DSS) following the written transaction record **175**, continuing the gap with or without separator signals **180** until a subsequently received synchronized transaction **176** is written to the magnetic tape following the gap or separator signals. Thus, the data is written to magnetic tape **14** immediately, for example, in a "backhitchless flush", or "BF" type of operation.

The controller **18** saves the provided data at the buffer **30**. In one example, the data remains in the buffer at the original location at which it was written, and the data at that address is protected from being overwritten by succeeding data. In another example, the data is moved to another address of the buffer which is designated for data that is saved and is not to be overwritten. In still another example, buffer **30** comprises multiple buffers, and the data, as it is written to magnetic tape, is also transferred from a first buffer to a second buffer for saved data.

Thus, as the data is supplied to the magnetic tape drive **10,** it is written to magnetic tape, and is saved at the buffer **30**.

During the same operation, the controller operates the buffer **30** and the recording system to provide saved data from the buffer **30** to cause another separate set of the plurality of write heads to rewrite the saved data to other tracks of the magnetic tape in a continuous arrangement. In the example of FIG. **6A**, a transaction **174** that had been written to BF wrap **170** and saved, is written to a rewrite wrap **190**. The transactions are rewritten without the extended gaps of the BF wrap, thereby saving time when the transactions are read. Thus, during the same operation, the separate sets of write heads, write data to magnetic tape, and rewrite saved data to the magnetic tape, perhaps simultaneously writing with the separate sets of write heads.

Since there is typically a wait between synchronized transactions from the host system **20** of FIG. **1**, leading to the long gaps **180** between transactions, the buffer **30** empties more rapidly when rewriting data to the rewrite wrap, than new data is received from the host system.

The rewriting is therefore a subset of the time that BF writing is occurring. As the result, the rewriting may wait until enough data has been saved to begin rewriting. Even so, the buffer is likely to run out of data to rewrite. At this point, the rewriting stops. New data transactions

may continue to be written to the BF wrap. Alternatively or additionally, a backhitch may occur to a previous position on the BF wrap, such that the new data transactions can overwrite BF data transactions that have been rewritten.

Once enough data to begin rewriting has been written to the BF wrap and has been saved, a backhitch or a forward movement may be conducted to the end of the previously rewritten transaction, and the next data that had been saved but not rewritten is rewritten to the rewrite wrap. The data transactions that had been written to the BF wrap and not rewritten cannot be overwritten unless temporarily written elsewhere, as will be discussed. Thus, if such data transactions are encountered, the BF writing must be stopped until the data transactions are rewritten.

In the example of FIG. **6A**, the buffer runs out of data to rewrite upon rewriting data transaction **174**. BF transaction **175** had been written to the BF wrap **170**, and, while the system waits for more data to accumulate in the buffer to rewrite, for example, half of the buffer capacity, BF writing may continue, as discussed above, writing transaction **176** to the BF wrap. In one alternative, a backhitch **191** may occur after transactions **175** and **176**, etc., are written to the BF wrap, and saved, and after enough data has been saved to begin rewriting. In backhitch **191**, the tape is moved to the last rewritten transaction **174**. However, BF writing must then be stopped, since transactions **175**, **176**, etc., of BF wrap **170** have not been rewritten, and are not overwritten. Alternatively, the transactions may be temporarily written elsewhere, allowing the initial copy to be overwritten, as will be discussed. Then, the saved transactions **175'**, **176'**, etc., are rewritten to the rewrite wrap **190**, appended to transaction **174**, and the appearance will be as though backhitch **192** had occurred for the rewrite wrap. Subsequent to rewriting the saved data

transactions **175'** and **176'**, etc., to the magnetic tape to a rewrite wrap **190**, the data of the BF wrap **170** that had been saved and rewritten, may be overwritten, shown in the subsequent state as wrap **170'**. Thus, after a backhitch, the writing of new data to the BF wrap **170'** may resume, and the data is once again written to magnetic tape **14** immediately in the backhitchless flush type of operation. Alternatively, a backhitch **193** may occur when the buffer runs out of data to be rewritten, the backhitch to a previous position on the BF wrap **170'**, at a point where the data transactions have been rewritten, and the data may now be overwritten. BF writing may then continue, as discussed above, writing transactions, up to transaction **185** of the BF wrap. When enough data has been saved to begin rewriting, the tape is moved forward to the end of the last rewritten transaction **174**. If a transaction **175, 176** of BF wrap **170** is encountered that has not been rewritten, the BF writing must be stopped, since transactions **175, 176**, etc., have not been rewritten and are not overwritten. Alternatively, the transactions may have been temporarily rewritten elsewhere and thus may be overwritten. The tape is moved forward to the end of the last rewritten transaction **174**. Then, the saved transactions **175', 176'**, etc., are rewritten to the rewrite wrap **190**, appended to transaction **174**, and the appearance will be as though backhitch **192** had occurred for the rewrite wrap. Subsequent to rewriting the saved data transactions **175'** and **176'**, etc., to the magnetic tape to a rewrite wrap **190**, the data of the BF wrap **170** that had been saved and rewritten, may be overwritten. The data saved in the buffer **30** of FIG. **1** may also be overwritten. Thus, the writing of new data to the BF wrap **170'** may resume, and the data is once again written to magnetic tape **14** immediately in the backhitchless flush type of operation.

The performance of the arrangement of the embodiment of FIG. **6A** is limited by the requirement to prevent overwriting data that has not yet been rewritten.

In one alternative, referring additionally to FIG. **6B**, data saved as accumulated in buffer **30** of FIG. **1** and discontinuously written to wrap **170** of FIG. **6A**, such as data transactions **175**, **176**, etc., are temporarily rewritten, potentially while the discontinuous writing of data transactions continues. In the example of FIG. **6B**, data transactions **175"** and **176"** are temporarily rewritten at wrap **190'**, a distance from the location of finally rewritten data transaction **174**. At an appropriate time, either by backhitch **191**, or by writing discontinuous data transactions and/or temporarily rewritten transactions on another wrap in the reverse direction, the recording system finally rewrites data transaction **175'**, **176'** on wrap **190**, and is able to simultaneously begin writing new discontinuous data transactions on wrap **170**, overwriting the original discontinuous data transactions **175** and **176**.

FIG. **7** illustrates an alternative arrangement, employing a seek to a different BF wrap, to avoid the necessity of waiting to overwrite data that has not been rewritten.

In the example of FIG. **7**, data transactions are written to BF wrap **198**, including transactions **202** and **203**, and saved, and saved data transactions are written to rewrite wrap **199**, including transactions **200**, **201**, and **202'**. In the example, the buffer runs out of data upon rewriting data transaction **202'**. A seek **210** is conducted to an alternate BF wrap **211**. The seek may be direct, or may involve forward or backward motion of the tape.

The seek allows the writing of BF transactions to continue at alternate wrap **211**, while the saved, but not rewritten, BF transaction **203** is maintained on wrap **198**. As an example, BF transactions are written to alternate wrap **211**, including transaction **212**. When enough data has

been saved to begin rewriting, a seek **216** is conducted back to the rewrite wrap **199**, and the tape is moved to the end of the last rewritten transaction **202'**. Then, the saved transactions, including transaction **203'**, are rewritten to the rewrite wrap **199**, appended following transaction **202'**, and the appearance will be as though backhitch **217** had occurred for the rewrite wrap. The writing of new data to the BF wrap **198** may resume, shown in the subsequent state as BF wrap **198'**. The resumed writing, in the example, begins with BF data transaction **213**, and the data is once again written to magnetic tape **14** immediately in the backhitchless flush type of operation.

At the next instance of the buffer running out of data to be rewritten to the rewrite wrap, the tape may be moved, such as a backhitch to a previous position on the BF wrap **198'** at a point where the data transactions have been rewritten, and the data may now be overwritten, up to a point where data transactions are encountered that have not been rewritten, and that cannot be overwritten. Alternatively, BF writing may continue forward at the BF wrap **198'**, as discussed above with respect to FIG. **6A** and **6B**, writing transactions, up to the end of tape for that wrap, or until data transactions are encountered that have not been rewritten, and that cannot be overwritten. Still alternatively, a seek may again occur to the alternate BF wrap **211** of FIG. **7**, again up to the end of tape for that wrap or data transactions are encountered that have not been rewritten, and that cannot be overwritten.

Thus, although not necessary, the performance improves with one seek **210** to another track, allowing BF writing to occur back to the longitudinal position where the rewriting ended. The seek allows the BF writing to resume immediately on the alternate wrap **211**. The seek back **216** allows the rewriting to continue on the original rewrite wrap **199**, and allows the BF writing to again resume immediately back on the first wrap **198'**.

Alternatively, BF writing may continue on BF wrap **198**, and saved accumulated data transactions may be temporarily rewritten subsequently on wrap **199**, or rewritten subsequently on a wrap related to wrap **211**. Then, the original discontinuous data transactions may immediately be overwritten with the final rewriting of data transactions **202'**, **203'**, etc.

The BF wraps and rewrite wraps may be provided in alternative arrangements. In the example of FIGS. **8A** and **8B**, the BF wraps are allocated, as are the rewrite wraps. Thus, the data is from the buffer **30** of FIG. **1** to one of the wraps in a sequence of the wraps, and the saved data is rewritten to another of the wraps that is offset from the one of the wraps.

FIG. **8A** represents a "pass 1" of rewriting saved data to a rewrite wrap **240**. Wraps **241**, **242** and **243** represent other rewrite wraps. During the same operation, the received data is written to BF write wrap **245**. Wraps **246**, **247** and **248** represent other BF write wraps which are offset from the rewrite wraps such that the separate sets of the tape write heads may simultaneously write at a BF write wrap and a rewrite wrap. If an alternate BF wrap is employed as discussed above, it will comprise one of the BF wraps **245**, **246**, **247** and **248**. In the example of the "pass 1", BF write wrap **246** is the alternate BF wrap.

FIG. **8B** represents a "pass 2" of rewriting saved data to the rewrite wraps, illustrating rewrite wrap **241**. Wrap **240** in the example has already been rewritten with saved data. During the same operation, the received data is written to BF write wrap **246**, which is offset from the rewrite wrap **241** such that the separate sets of the tape write heads may simultaneously write at a BF write wrap **246** and the rewrite wrap **241**. If an alternate BF wrap is employed as discussed above, it will comprise one of the BF wraps **245**, **246**, **247** and **248**. In the example of the "pass 2", BF write wraps **247** or **248** may be the alternate BF wrap.

The wrap offset is such that separate BF wraps and rewrite wraps are available at the tape write head offset for the separate sets of tape write heads, and may comprise the index positions of FIG. **5**, where, at each index position, the separate sets of write heads write the two wraps, or comprises other suitable offset arrangements. Referring to FIGS. **4** and **5**, in the arrangement of FIG. **5**, alternate write heads **117** may be selected for the two wraps, or write heads **117** at opposite ends of the tape head **23** may be selected for the two wraps. Other arrangements, such as selecting adjacent pairs of heads for each wrap, may alternatively be employed.

In a further embodiment, the controller **18** of FIG. **1** selectively operates the buffer **30** and the recording system to provide data from the buffer to cause a separate set of the plurality of write heads **117** of FIG. **4** to write the provided data to tracks of magnetic tape, saving the provided data; and, during the same operation, operates the buffer **30** of FIG. **1** and the recording system to provide saved data from the buffer to cause another separate set of the plurality of write heads to write the saved and provided data to other tracks of the magnetic tape, for example, as illustrated by FIG. **6**, FIG. **7**, or FIG. **8**; and, selectively operates the buffer **30** of FIG. **1** and the recording system to provide data from the buffer to cause the plurality of write heads **117** of FIG. **4** to write provided data to tracks of magnetic tape, comprising up to all sets of the write heads, as illustrated by "full head" data of FIG. **9**, with the pattern of write heads similar to that illustrated in FIG. **8**. Thus, if there is no synchronized data or no need to write data to magnetic tape, save the data and subsequently rewrite the data to the tape, then all the heads may selectively be employed to write in parallel, e.g. to wraps **250** and **251** of FIG. **9**. If the data comprises a pattern of synchronized data, the controller selectively writes the data to a BF wrap **245** of FIG. **8**, and rewrites saved data to rewrite wrap **240**. The selectivity may occur on the

basis of patterns of data transactions, or, more likely, on the basis of the data that will be provided to the tape cartridge. Thus, the host system or operator may indicate that the data for the magnetic tape cartridge **11** of FIG. **1** will be synchronized data, or will not be synchronized data, and the controller **18** selects the write heads to write the pattern of FIG. **8A** or of FIG. **9**, accordingly.

In a still further embodiment, wherein the magnetic tape drive additionally comprises a plurality of read heads **117** in FIG. **4** for reading from magnetic tape while the magnetic tape is moved longitudinally with respect to the plurality of read heads, the controller additionally selectively operates the read data system **134** of FIG. **1** to read one of the wraps at a time with one set of the plurality of read heads, when the data is written as rewritten data, for example, as illustrated in the pattern of FIG. **8A** and FIG. **8B**; and selectively operates the read data system to read a plurality of the wraps at a time with the plurality of read heads when the data is written as full write data, for example, as illustrated in the pattern of FIG. **9**. The indication whether the data is in the form of full write data or in the form of rewritten data may be in the index or similar information at the beginning of the tape.

FIGS. **10A** and **10B** illustrate an alternative arrangement of the use of the wraps for writing data, and rewriting saved data. In a still further embodiment, the wraps are accessed in a sequence, such that a wrap having the data to be saved follows in the sequence a wrap at which the data is rewritten, such that a continuous string of wraps are first written as BF wraps with the data to be saved, and then are overwritten with the rewritten data.

FIG. **10A** represents a "pass 1" of rewriting saved data to a rewrite wrap **270**. Wrap **271** comprises a BF wrap to which the received data is written, during the same operation. In the example of the "pass 1", wrap **272** is the alternate BF wrap.

FIG. **10B** represents a "pass 2" of rewriting saved data to the rewrite wraps, illustrating the overwriting of former BF wrap **271** as rewrite wrap **271'**. Wrap **272'** in the example now becomes the BF write wrap. If an alternate BF wrap is employed as discussed above, it will comprise one of the remaining previously unwritten wraps, such as wraps **273**. Thus, the wrap having the data to be saved **272'** is next in the sequence from a wrap **271'** at which the data is rewritten, such that a continuous string of wraps are first written as BF wraps with the data to be saved, and then are overwritten with the rewritten data.

The controller **18** of FIG. **1** additionally operates the plurality of read heads **117** of FIG. **4** and the read data system **134** of FIG. **1** to read one of the wraps **270'**, **271'** of FIG. **10B** at a time with one set of the read heads.

FIG. **11** comprises a flow chart of an embodiment of the computer implemented method of the present invention. Data is received at step **300**, and stored in the buffer(s) in step **301**, such that the data may be written to tape. In step **303**, the controller determines whether the write operation will be a multi-set write, using sets of write heads, or a full head write. If it is a full head write, as discussed above, in step **305**, the controller selects the full head write, operating the buffer **30** of FIG. **1** and the recording system to provide data from the buffer to cause the plurality of write heads **117** of FIG. **4** to write provided data to tracks of magnetic tape, comprising up to all sets of the write heads, as illustrated by "full head" data of FIG. **9**.

If step **303** indicates a multi-set write, such as for synchronized transactions, in step **307**, the controller **18** of FIG. **1** selectively operates the buffer **30** and the recording system to provide data from the buffer to cause a separate set of the plurality of write heads **117** of FIG. **4** to write the provided data to tracks of magnetic tape. In step **309** of FIG. **11**, the controller saves the provided data, the operation continuing for the transaction until the full transaction has been both written to magnetic tape and saved, as indicated by step **310**. After the transaction is both written to magnetic tape and saved, in step **311**, the controller **18** of FIG. **1**, additionally, for the synchronized data transaction, returns a command complete at interface **21** upon completion of the writing a synchronized transaction to tracks of magnetic tape in a discontinuous manner. In step **315** of FIG. **11**, the controller leaves an elongated gap, comprising an unrecorded gap and/or written separator signals to the magnetic tape following the written synchronized transaction, continuing the gap with or without separator signals until a subsequently received synchronized transaction is written to the magnetic tape following the separator signals or gap. During the same operation, the controller operates the buffer **30** of FIG. **1** and the recording system to provide saved data from the buffer to cause another separate set of the plurality of write heads to write the saved and provided data to other tracks of the magnetic tape. Thus, in step **320** of FIG. **11**, the controller determines whether enough data has been saved to warrant beginning the string of continuous rewritten transactions, by providing and rewriting the saved data. If not, step **321** indicates a wait for at least one additional transaction to be saved, and the determination is repeated. In this example, the determination is made as based on a threshold, for example, of the number of transactions or the amount of data or percentage of buffer capacity, that has been

saved. Alternatively, a count may be maintained, and a counter may indicate when it reaches its full count.

When the controller is ready for rewriting in step **320**, the controller, in step **322**, selects the set of write heads and provides data from one or more selected separate data flow outputs **125**, **126** of the buffer **30**, of FIG. **1**, for example, via a selected recording channels **132** and **133**, to the selected set of write heads **117** to rewrite the saved data at a rewrite wrap. Then, in step **325** of FIG. **11**, the controller releases the saved transaction in the buffer to allow overwrite of the data by new data transactions to be saved. Further, in step **326**, the controller releases the same transaction at the BF wrap to allow overwrite of the data by new data transactions to be written to the tape. The process returns to step **320** to determine if the process is still ready for rewriting, or whether, for example, the buffer has run out of data to be rewritten. Step **320** also is the point at which the determination is made to move the tape to another position on the BF wrap and/or seek to an alternate BF wrap and to continue to save data to be rewritten, as discussed above.

Step **330** provides the option of temporarily rewriting data that had been originally discontinuously written and also saved in the buffer. Since the data is recorded on tape elsewhere, the original discontinuously written data may be overwritten. Thus, when data is being rewritten on the alternate track, new data may be discontinuously written at the same time, overwriting the original discontinuously written data.

Thus, step **331** comprises temporarily rewriting the data transaction. A transaction is selected for temporary rewriting based on its position laterally offset with respect to the location for rewriting transactions that are to be finally rewritten. When the data has been temporarily rewritten, step **332** releases the original discontinuously written transaction so that it may be overwritten.

The temporarily rewritten data transaction is ultimately released in step **326** after the saved data transaction has been finally rewritten to a rewrite wrap in step **322**.

The illustrated components of the magnetic tape drive and recording system of FIG. **1**, and the arrangement of the tape head of FIG. **4** may be varied, combined, or combined functions may be separated, as is known to those of skill in the art. The illustrated steps of FIGS. **11** may be altered in sequence, omitted, or other steps added, as is known to those of skill in the art.

While the preferred embodiments of the present invention have been illustrated in detail, it should be apparent that modifications and adaptations to those embodiments may occur to one skilled in the art without departing from the scope of the present invention as set forth in the following claims.

I claim: